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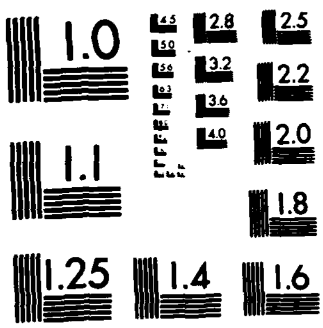

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WAVE CHARACTERISTICS OF TEMPERATURE INVERSION PROCESS OF NIGHTTIME RADIATION

by

Zhou Mingyu and Zhang Yi

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WAVE CHARACTERISTICS OF TEMPERATURE INVERSION PROCESS OF NIGHTTIME RADIATION

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I. Foreword

At nighttime, it is quite difficult to maintain a stable atmospheric boundary layer, since the meteorological elements often vary with time. Therefore, the study of nighttime characteristics of the atmospheric boundary layer is important, especially the characteristics and variation rule of the temperature inversion process of radiation regarding the fundamental theoretical studies and practical problems, such as transport and diffusion of atmospheric contaminants.

By considering the horizontal homogeneity conditions, the heat equation of the near-ground atmosphere can be expressed by the following equation:

$$\frac{1}{C_p\rho}(\mathrm{div}R + \mathrm{div}H) = -\frac{\partial T}{\partial t}. \qquad (1)$$

By definition:

$$C_A = -\frac{\partial T}{\partial t}, \quad (2)$$

$$C_R = \frac{1}{C_P\rho}\,\mathrm{div}\,R = \frac{1}{C_P\rho}\frac{\partial R}{\partial Z}, \quad (3)$$

$$C_H = \frac{1}{C_P\rho}\,\mathrm{div}\,H = \frac{1}{C_P\rho}\frac{\partial H}{\partial Z}, \quad (4)$$

Therefore, we have $$C_A = C_R + C_H. \quad (5)$$

In the equations above, T is the absolute temperature of the atmosphere; R is the net radiant flux; H is eddy heat flux; C_P is constant pressure ρ specific heat of the atmosphere; is density of the atmosphere; t is time; Z is altitude; C_A is actual rate of temperature decrease of the atmosphere; C_R is radiant cooling rate; and C_H is rate of heat increase of the eddy.

Funk had obtained data for R and C_R of nighttime segments near the ground; some useful results were attained [1]. However, from Funk's data the radiant characteristics of the entire nighttime segments were not apparent; he did not discuss the relationship between C_R and variation of meteorological elements and discussions on the two aforementioned problems.

II. Observation Methods

In summer and fall (July through October) of 1980, experiments were conducted during cloudless, breezy nights. The observation site was a 325-meter meteorological tower in a north Beijing suburb at the Institute of Atmospheric Physics of the Chinese Academy of Sciences; the ground surface was covered with shallow grass. There were 15 layers of observations of temperature and wind speed at the tower; there were three layers of additional synchronous observations below the tower near the ground surface. The altitudes were, respectively, 0, 0.5, 1.5, 9.7, 15, 33, 48, 63, 80, 103, 120, 140, 160, 180, 200, 240, 280 and 320 meters; the radiant and temperature observations were conducted at 0.5 and 1.5 meters. Refer to Literature [2]

for details of structure and instruments at the meteorological tower. The observation accuracies of temperature and wind speed were 0.1°C and 0.2 meter per second.

During experiments, an Australian-made model CN_2 portable actinometer (for measurement of net light radiation) was used with sensitivity of 29.73 millivolt·square centimeter·minute per calorie. After coupling with a USSR-made radiant meter, the conversion coefficient was 0.0011 calorie/square centimeter·minute·partition line. A hemispherical polyethylene film was attached at each of the upper and lower surfaces of the detection head of the instrument. For wind speed less than 15 meters per second, the error was only 1 percent; basically the wind speed has no influence on the observation measurement. Therefore, observation requirements of wave characteristics of C_R can be guaranteed.

III. Experimental Results

1. Wave characteristics of the temperature and net radiation in the nighttime temperature inversion process: Earlier, people understood very well the decreasing trend and wave characteristics of temperature in the inversion process. Our data show that temperature curves of various layers have a similar trend of lessening variation; curves of the temperature reduction rate of various layers have relatively similar waveforms for periods and phases. The height increase of the inversion layer is not uniform with characteristics of wave growth; the period is about one hour. The net radiation flux R near the ground is closely related to ground temperature T_g and near-ground air temperature T. The net radiation fluxes $R_{0.5}$ and $R_{1.5}$ at 0.5 and 1.5 meters observed by us have a similar variation trend and wave characteristics as temperature $T_{1.5}$ (at 1.5 meters) and ground temperature T_g. We noted that the absolute values of $R_{1.5}$ of all times are greater than $R_{0.5}$.

2. Characteristics of C_R and its relationship with C_A: Figure 1 is a time variation diagram of C_A and C_R. We can see the following from the diagram: (1) Clear wave characteristics are shown in C_A and C_R curves. (2) A certain periodicity exists in C_A and C_R curves. The main period of C_R is

about 1 hour; we noted that all night long there was a period of about 1 hour. (3) When the wind-speed gradient is relatively small and the eddy exchange is relatively weak, there were relatively consistent period and phase between C_R and C_A curves. For example, in curves of the time segments of 21^{50} to 23^{50} hours, the periods and phases were quite consistent; in these time segments, the wind-speed gradients at 1.5 meters were relatively small or equal to zero. We also noted that in the entire nighttime duration (in the time segments with geenrally higher wind speed, the periods and phases of C_R and C_A were often inconsistent.

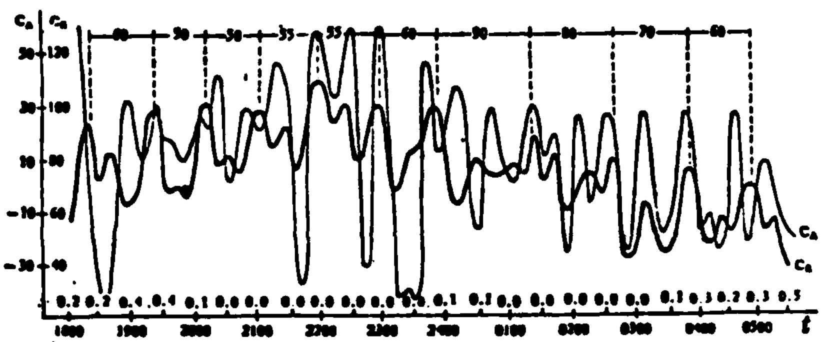

Fig. 1. Time variation curves of C_R and C_A on 6/10 to 7/10 (Unit at 10^{-3}°C/minute): values above the abscissa are $\partial u/\partial z$ (second^{-1}) at 1.5-meter altitude.

3. Characteristics of C_g (the rate of temperature decrease at the ground) and its relationship with C_R; Fig. 2 is the time variation diagram of C_R and C_g; here $C_g=(-\partial T_g)/\partial t$. We can see the following: (1) C_g has clear wave characteristics and the main period is about 1 hour. (2) There are relatively consistent periods and phases in C_R and C_g curves. These show that C_g and C_R are closely realted.

4. Relationship between Richardson number Ri (of the atmospheric layers) and C_g: Drazin [3] studied theoretically the dynamic stability problem of wind

tangential shift in a stable boundary layer; he deduced that the condition of instability is $Ri \leq 0.25$. Later, quite a few researchers applied this theory to discuss the phenomenon occurring in the boundary layer; even some weather phenomena are related to this instability process [4-6]. We discovered in observation experiments that under the background conditions of weak weather, this instability process of wind shift can rapidly vary the temperature and wind in the near-ground layer.

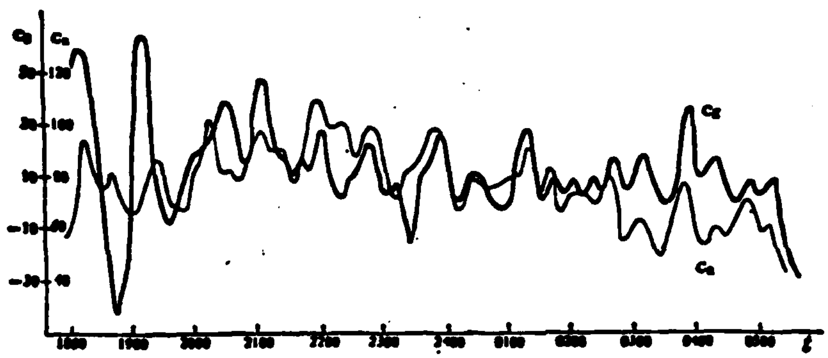

Fig. 2. Time variation curves of C_g and C_R from 6/10 to 7/10 (Unit at 10^{-3}°C/minute).

Figure 3 is a diagram showing the near-ground wind speed and temperature contours under the conditions that Ri numbers are, respectively, 0.19 and 0.22 at atmospheric layers of 100 to 120 meters, and 140 to 160 meters at 21^{43} hours and in the subsequent half hour. As the diagram shows that the wind speed and temperature (of near-ground layers) generally increase and the intensity of the temperature inversion is weakened, we noted that the duration of increasing temperature and wind-speed were about half an hour after 22^{15} hours; temperature adn wind speed were decreased, and the intensity of the temperature inversion was gradually intensified.

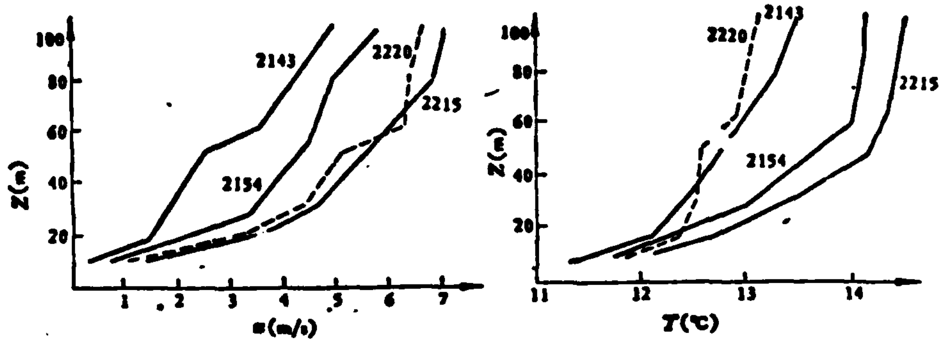

Fig. 3. Temperature and wind speed contours diagram (17/10).

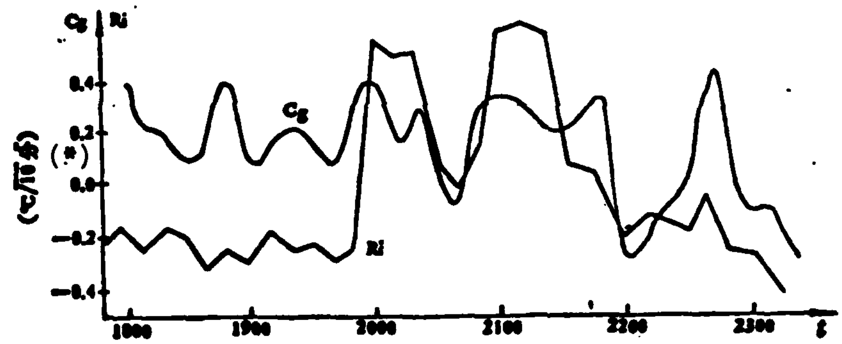

Fig. 4. Ri number curves (17/10) at C_g and 1.5- to 15-meter atmospheric layer.
Key: (*) Minutes.

Does the dynamic instability process of the wind tangential shift have a time variation rule? Is the dynamic instability process of wind shift related to the decrease rate of the ground temperature? Figure 4 is the relationship diagram of the Ri number and C_g. The figure reveals the following: (1) The time variation of the Ri number is wavy in shape; the minimum value of the broken line of the fluctuation almost satisfies the instability condition of

tangential shift. (2) The main period of the time variation curve of the Ri number is about 1 hour; this means that dynamic instability of tangential shift (of wind) causes downward transmission of momentum and heat to increase temperature and wind speed (of the near-ground atmospheric layer); this process occurs regularly and repeatedly. (3) The Ri number curve and C_g curve have relatively consistent periods and phases. This illustrates that the intensified eddy activities due to dynamic instability of wind tangential shift have a negative feedback function on near-ground temperature variation.

IV. Discussion

With the above results, it can be considered that the complex physical process in the nighttime atmospheric boundary layer includes periodic wavy motions; this periodic wavy motion may occur in different layers; this is the result of mutual activities, mutual restraints, and mutual adjustments between temperature and wind fields caused mainly by long-wave radiation at the ground surface.

The long-wave radiation at the ground surface may form a near-ground temperature inversion layer; the formation and growth of the inversion layer hinder the vertical exchange of eddies. The momentum of downward transmission from the upper layer is piled up at the top of the temperature inversion layer, and ground friction also constantly consumes momentum. Therefore, the wind speed gradient of the inversion layer is increased. When the tangential shift of the wind is increased to a certain degree, dynamic instability will occur. The energy of tangential shift of the wind is quickly converted into eddy energy. Therefore, the vertical exchange of eddies rapidly increases, causing rapid increase of heat and momentum fluxes of downward transmission. Thus, within a short time duration, the near-ground temperature and wind speed increase, and also the ground temperature increases or the rate of decrease is gradually slowed down. This eddy activity also applies negative feedback to the cooling function of ground radiation to somewhat slow down the cooling of radiation. The aforementioned adjustment process homogenizes the vertical variation (or slows down the change) of the meteorological elements. Since

long-wave radiation always exists and the ground temperature decrease intensifies gradually, the aforementioned process will repeatedly appear; the process may appear several times throughout the night. This is the reason causing wavy variations of nighttime weather elements (such as temperature in the inversion process and altitude of the inversion layer); this is also the reason for regular wavy variations of the C_R, C_A, C_g and Ri number

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